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(19)

(54) ELECTRON BEAM RECORDING OF SIGNALS ON THERMOPLASTIC FILM

(71) We, DECCA LIMITED, a British Company, of Decca House, 9 Albert Embankment, London, SE1 7SW, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to recording signals and particularly to a method of recording a signal, particularly, but not exclusively a television picture signal, in the form of a spatially modulated groove formed in a thermoplastic disc.

One major application of the present invention is the recording of a television signal on a medium which can be used in the production of video discs, that is to say, discs which can be played back by means of a stylus that physically engages a groove in the disc. However the invention is directed to the production of a recording on a thermoplastic film which may be in the form of a disc and is not limited to the subsequent production of a video disc after, for example, metallisation of the thermoplastic disc to form a master matrix for the production by suitable presses of mechanically playable video discs.

The invention relates generally to a method of recording, which involves the modulation of a beam of electrons which is brought to a focus and directed at a thin thermoplastic film disposed on an electrically conductive substrate. This expedient leads to the deposition of a track of charge on the thermoplastic film and the excess pressure which is exerted on the surface of the film by virtue of the forces between the deposited charge and the conductive substrate produces a local radius of curvature, which is determined by the local charge density, after the film is softened by heating. Accordingly the contours of the film can be formed in accordance with the time variation of the intensity of the beam and subsequent to the deposition of charge and the heating of the film, which may occur either before or after the deposition of charge, the film may be cooled so as to freeze the film into the contoured shape in which it is formed by the combined effects of the deposition of charge and the softening of the film by heating.

A number of methods of this type have been hitherto proposed. For instance, one known method involves the scanning of a surface of a thermoplastic film using an intensity modulated beam of electrons so as to produce a pattern of charge which defines a composite diffraction grating. Such grating, upon transmission of light therethrough produces a visible pattern representative of the electric signals used in modulating the electron beam.

However, neither this nor any of a number of other known methods involves the production of a suitable pattern of charge on a film of thermoplastic material by using a modulated electron beam which pattern when heated causes the formation of a groove of such dimensions and profile as to be playable mechanically by a stylus which physically engages a corresponding groove in a record produced from the film.

The present invention provides for the recording of a television picture signal or other signal by directing a beam of electrons at a thermoplastic film carried on an electrically conductive substrate which may be a thin planar chromium film carried on a glass disc. The thermoplastic film is traversed relative to the beam and this is preferably achieved by rotating the film in its plane and simultaneously translating it in its plane so that the point of impingement of the beam of electrons on the surface of the film follows a spiral path. The intensity of the beam is modulated in accordance with the signal to be recorded. Preferably the beam is modulated by a frequency modulated carrier signal which carries a television picture signal. The modulation of the electron beam in this manner produces a lengthwise variation in the

density of the deposited charge. In addition the intensity of the beam and its impingement on the track are controlled so that the charge distribution across the width of the track, that is to say transverse the direction of progression of the spiral path, is least at the edges of the track and greatest in the centre. There are disclosed several methods of achieving such a charge distribution. In any event it is desirable to ensure that charge is deposited over the whole region which will correspond to the area within the boundaries of the groove that is formed subsequent to both the deposition of charge and the softening of the thermoplastic film by heating. One possibility is to oscillate the beam transversely at such a frequency, substantially higher than the highest frequency of variation of the intensity of the beam in accordance with the video signal, that is sufficient to cover every point on the track of charge that is deposited at least twice. It is possible to vary the frequency of transverse oscillation in accordance with the effective tangential velocity of the film where the beam strikes it but it is also possible to select the frequency of oscillation so high, for example at 50 MHz or thereabouts, that the frequency of transverse oscillation is always high enough to ensure the double deposition of charge. A further possibility however consists of introducing astigmatism deliberately into the focussing of the electron beam so that the effective diameter of the beam is relatively narrow in the sense along the direction of progression of the track but is substantially wider in the sense across the track.

Either before or after the charge is deposited the film is heated so that the variable electrostatic attraction between the deposited charge and the conductive substrate deforms the surface of the film into the required shape. On cooling of the disc the deformations are frozen. Subsequently if desired the recorded disc can be metallised and otherwise treated so as to produce a nickel master which can be used in a press for the reproduction of discs on a large scale.

In accordance with one aspect of the invention, there is provided a method of recording a signal, comprising the steps of: directing a beam of electrons at a thin film of electrically resistive thermoplastic material which is supported by an electrically conductive substrate, modulating the intensity of the beam in accordance with the said signal, moving said film relative to said beam and thereby causing said beam to deposit on the film a continuous track of electric charge of which the density varies along the direction of progression of the track in accordance with the modulations of the intensity of the beam, focussing said beam to produce a focus at the film having an effective diameter (as hereinafter defined), in a sense along the direction of progression of the track, which is substantially less than the shortest wavelength in said signal in the form of the charge density variations along the track, producing astigmatism in said beam so that the said focus is elongate in a direction transverse the direction of progression of said track and has in the transverse direction second effective diameter (as hereinafter defined) which is a substantial fraction of the width of the track, so as thereby to cause said track to be of a width which is significantly wider than the first-mentioned effective diameter and has a charge density which is substantially greater in the middle of the track width than at the edges thereof, heating said film to soften it at least where the charge is deposited whereby a groove of which the depth varies in accordance with said signal to be recorded is formed in the film, and cooling the film.

In accordance with another aspect of the invention, there is provided a method of recording a signal comprising the steps of aiming an electron column so as to direct a beam of electrons at a thin film of electrically resistive thermoplastic material which is supported by an electrically conductive substrate, moving said film relative to said beam and thereby causing said beam to deposit a continuous track of electric charge on the film, generating a control signal for modulating the intensity of the beam in accordance with the said signal to be recorded, focussing said beam to produce a focus at the film having an effective diameter (as hereinafter defined), in a sense along the direction of progression of the track, which is substantially less than the shortest wavelength in said signal, as recorded in the form of the charge density variations along the track, controlling said beam and thereby causing said track to be of a width which is significantly wider than said effective diameter and to have a charge density which is substantially greater in the middle of the track width than at the edges thereof, coupling, through a high voltage coupling, said control signal to said electron column so as to modulate the intensity of said beam in accordance with the said signal to be recorded, heating said film to soften it at least where the charge is deposited, whereby a groove of which the depth varies in accordance with said signal to be recorded is formed in the film, and cooling the film.

In accordance with yet another aspect of the invention, there is provided a method of recording a signal comprising the steps of directing a beam of electrons at a thin film of electrically resistive thermoplastic material which is supported by an electrically conductive substrate, modulating the intensity of the beam in accordance with the said signal, moving said film relative to said beam and

thereby causing said beam to deposit on the film a continuous track of electric charge of which the density varies along the direction of progression of the track in accordance with the modulations of the intensity of the beam, focussing said beam to produce a focus at the film having an effective diameter (as hereinafter defined), in a sense along the direction of progression of the track, which is substantially less than the shortest wavelength in said signal in the form of the charge density variations along the track, oscillating said beam from side to side across the direction of progression of said track at a constant wobble frequency which is sufficiently high to ensure the deposition of charge at least twice at every point within the width of the track, blanking said beam at the extremities of its side to side movement, controlling the intensity of the beam so that the track has a charge density which is substantially greater in the middle of the track width than at the edges thereof, said oscillating, blanking and intensity controlling being such that the track is of a width which is significantly greater than said effective diameter, heating said film to soften it at least where the charge is deposited whereby a groove of which the depth varies in accordance with said signal to be recorded is formed in the film, and cooling the film.

In accordance with a further aspect of the invention, there is provided a method of recording a signal comprising the steps of aiming an electron column so as to direct a beam of electrons at a thin film of electrically resistive thermoplastic material which is supported by an electrically conductive substrate, moving said film relative to said beam and thereby causing said beam to deposit on the film a continuous track of electric charge, focussing said beam to produce a focus at the film having an effective diameter (as hereinafter defined) in a sense along the direction of progression of the track, which is substantially less than the shortest wavelength in said signal in the form of the charge density variations along the track, oscillating said beam from side to side across the direction of progression of said track at a wobble frequency which is sufficient to ensure deposition of charge twice at every point within the width of the track, blanking the beam at the extremities of the oscillatory movement of the beam, generating a first control signal for modulating the intensity of the beam in accordance with said signal to be recorded, said first control signal comprising a carrier signal which is modulated in accordance with said signal to be recorded, amplitude modulating a signal oscillating at a frequency greater than, and harmonically related to the wobble frequency, in accordance with said first control signal, to produce a second control signal, passing said second control signal through a high voltage coupling, deriving from the output of the high voltage coupling a third control signal at the wobble frequency, for oscillating said beam, and a fourth control signal for varying the intensity of the beam at a frequency which is twice the wobble frequency so that the beam intensity has an amplitude which is greatest in the middle of the track width and so that the track is of a width which is significantly greater than said effective diameter, and detecting the envelope of the said output of the high voltage coupling to reconstitute the first control signal for modulating the intensity of the beam, coupling said reconstituted first control signal, said third and said fourth signals to said electron column so as to effect said modulating, oscillating and intensity varying of said beam, heating said film to soften it at least where the charge is deposited, whereby a groove of which the depth varies in accordance with said signal to be recorded is formed in the film, and cooling the film.

Some embodiments of the invention will now be described by way of example, with reference to the accompanying drawings, in which:

Figure 1 is an explanatory diagram showing in longitudinal section the effect of depositing electric charge on a soft thermoplastic film;

Figures 2A, 2B and 3 illustrate profiles of grooves formed in a thin thermoplastic layer;

Figure 4 illustrates principally the mechanical features of an apparatus for recording signals on a thermoplastic film using electron beam scanning;

Figure 5 illustrates an electron beam column suitable for use in the apparatus disclosed in Figure 4;

Figure 6 is an explanatory diagram showing the effect of transverse oscillation of the beam of electrons;

Figure 7 is a series of wave form diagrams showing the development of signals which can be used for controlling the electron beam to produce the required profile of groove;

Figure 8 is an electronic schematic diagram illustrating a preferred embodiment for the production of the signals illustrated in Figure 7;

Figure 9 is a diagram illustrating the effects of astigmatism; and

Figure 10 is a schematic diagram of an alternative embodiment of the invention.

Figure 1 illustrates a thin film 1 of thermoplastic material disposed on the surface of an electrically conductive member 2 which is preferably a conductive disc. The film 1 is scanned by a focused electron beam, commonly called an electron probe, and the film is traversed in a manner particularly described hereinafter, the movement being illus-

trated in Figure 1 by the arrow 4. The electron probe 3 deposits a track of electric charge 5 on the surface of the film 1 and as the film is traversed the track follows a path determined by the particular relative movement of the probe and the film.

It is preferred to rotate the film in its plane and simultaneously translate it in order that the path that the track follows is a spiral of which the convolutions are centred on the centre of rotation of the film. The formation of a spiral track is desirable where recordings in the form of playable discs are to be derived from the master record made according to the present invention.

Where charge is deposited on the track, an excess pressure is exerted on the surface of the film 1 owing to the forces between the deposited charge 5 and the conductive disc 2. It is possible to calculate with considerable accuracy the pressure which is developed using the method of images in which there is assumed to be an equal charge 5*a* of opposite sense located below the surface of the conductor at the depth equal to the thickness of the film 1.

If the thermoplastic material is already or is now softened, the pressure due to the charge 5 produces a local radius of curvature which is determined by the local charge density and the pressure due to the charge 5 pulls the surface of the film towards the conductive substrate constituted by the disc 2 until the excess pressure is balanced by the surface tension of the film.

It will be apparent that in the highly charged regions of the track the surface of the film 1 is depressed and becomes concave whereas in the less highly charged regions the surface becomes convex.

Figures 2A and 2B illustrate the limits of possible profiles for a groove. Both illustrate the appearance of a groove after charge has been deposited and the film softened. Figure 2A illustrates the cross-section of a groove which would be formed if a uniformly dense strip of charge is laid along the track. In Figure 2A the groove has a profile which is only slightly curved over most of its width. Figure 2B illustrates a groove with a profile β which would be produced if a (theoretically unobtainable) line charge constituted the track. The profile β exhibits a well defined notch from which the sides of the groove slope convexly up to the surface of the film 1.

Figure 3 illustrates a groove of ideal characteristics although there may be slight variations from the ideal which would not substantially adversely affect the quality of a recording. The groove 6 illustrated in Figure 3 has a width w of the order of 3 to 10 microns, a depth h of approximately 0.5 microns with a rounded apex of which the radius of curvature r is about 1 micron. Such a groove is produced by a transverse distribution of charge density between the theoretical uniformly dense tracks (Figure 2A) and the theoretical line charge (Figure 2B. It has been found that it is possible to produce a profile of the form and dimensions shown in Figure 3 using an electron beam of which the intensity varies as a function of the distance from the centre of the beam in accordance with an approximately Gaussian distribution. Such a distribution is in fact the normal distribution for the intensity of an electron beam but herein lies the principal difficulty in the deposition of a track of charge that must form a groove and yet be capable of providing the groove with a longitudinal modulation of sufficient range to accommodate a wide band signal such as a television signal. The Gaussian distribution which would be necessary to produce a track of charge suitable for the formation of a groove 6 of the profile shown in Figure 3 would have to be relatively wide, of the order of 3 to 10 microns. That is to say, the spread must be wide enough to ensure that significant charge is deposited over the whole width of the track that corresponds to the groove that is ultimately formed. It is possible to provide a measure of the spread of a Gaussian curve by using the distance between the points that define a magnitude which is half the maximum magnitude of the Gaussian curve. In the following, including the Claims, the term "effective diameter" will be used to describe the "half-height" diameter. In order to produce a track of charge which is approximately 7 microns wide the effective diameter of the Gaussian curve should be of the order of 3.5 microns. The spread of the curve and accordingly the effective diameter must be greater if a wider groove is required. However the narrowest width of groove tends to be limited by the size of stylus that can be feasibly used to play back the corresponding groove in a derived pressing and the need to ensure that the stylus does reliably engage the groove.

Another factor which is important in determining the dimensions of the electron probe is the frequency that has to be recorded. The present invention provides for recording the signal that controls the intensity of the beam as a variation in the depth of the groove. The choice for the beam diameter is accordingly dictated by the shortest wavelength of the signal that is to be recorded on the film. On the assumption that a band width of 6MHz is required for recording, this band width corresponding to the band width required for colour television signals, the shortest wavelength that may have to be recorded is 1.3 microns. In order to record a wavelength of 1.3 microns the maximum effective diameter of the electron beam should not be greater than approximately half

this wavelength that is to say it should not exceed 0.65 microns.

Accordingly, if the diameter of the beam is of the order of 0.5 to 1 microns then it is insufficiently wide to produce a proper profile, in the transverse sense, for the groove. Moreover the groove should normally be of substantially constant shape but of variable depth at its centre.

The conflicting requirements for the effective diameter of the beam are resolved in the manner described hereinafter.

Before describing the features of a particular apparatus which can be used tc perform the present invention, it is convenient to discuss the physical requirements for the thermoplastic film. The term "thermoplastic" is not used in the specialised sense to denote any specific group of chemical compounds. A variety of substances, including various waxes, would be suitable. One thermoplastic material that is suitable is polystyrene which can be sprayed, painted or spun on to the conductive disc and if necessary partially scraped off to leave a film of suitable thickness. In general the thickness of the film should be approximately 10 microns or less.

The thermoplastic film should fulfil several physical requirements. The first is that it should be electrically resistive by which is meant in general a bulk resistivity of more than 10^{11} ohm cm. when fluid and more than 10^{16} ohm cm. when solid. The high electrical resistivity in the solid state is necessary so that the film can retain the deposited charge without significant leakage thereof for the duration of the scanning of the film by the electron probe. Preferably the thermoplastic is solid at ordinary temperatures in order to make recording convenient. A softening point between 60° Celsius and 100° Celcius is preferable. A fairly sharp softening point is also desirable. Typically the thermoplastic may be solid up to 65° Celsius but fluid at 85° Celsius. It is usually necessary to perform the scanning of the film by the electron probe in an evacuated chamber and for this purpose the vapour pressure of the film should be below 10^{-2} millimetres of mercury and preferably below 10^{-5} millimetres of mercury. The viscosity of the thermoplastic film in a softened state is preferably of the order of 10,000 centistokes. Moreover it should be stable in the presence of radiation so that during recording no perceptible radiation damage occurs. Another requirement which is appropriate in practice is that the thermoplastic film should be capable of receiving, for example by an evaporation method, a thin metal layer. Normally in the art of making gramophone records a master is provided with a thin metal layer for the purpose of making, after additional processing, a "mother" recording from which pressings can be made. The thin metal layer deposited on the master may be electro-plated and finally the metal "negative" would be removed from the thermoplastic film. Thus the thermoplastic film should be capable of releasing the metal layer without damage. However the range of possible thermoplastic materials can be extended considerably by the use of a release agent which may be sprayed onto the film before it is metallised.

Figure 4 illustrates the mechanical and some associated control elements of an apparatus suitable for recording according to the present invention. The apparatus includes an electron probe, that is to say a focused beam of electrons 10 which can be produced by an electron column of the form described with reference to Figure 5. The electron probe is directed vertically downwards towards a thin thermoplastic layer 11 carried on a conductive disc 12. The disc is mounted for rotation about its principal axis on a vertical shaft 13 Thus the rotation of the shaft 13 will rotate the film 11 in the plane of the film itself. The shaft 13 is mounted in a bearing 14 which is carried by a carriage 15 mounted for horizontal movement at right-angles to the axis of the vertical shaft 13. The shaft 13 and the bearing 14 may be removable together with the disc or the disc may be mounted by means of a kinematic support as described in British Patent Specification No. 1,406,254. In this embodiment the recording apparatus is wholly disposed within a vacuum chamber. Horizontal shafts 16 and 17 extend from the carriage 15 through sealed bearings 18 and 19 which are disposed respectively in the walls 20 and 21 of the vacuum chamber. The sealed bearings preferably take the form described in British Patent Specification No. 1,415,095. The horizontal shafts 16 and 17 are aligned along a translation axis through the point where the rotary axis of the shaft 13 intercepts the upper surface of the film 11. The carriage 15 can be tilted about the translation axis by means of a tilt lever 22 attached to the shaft 17. Translation of the carriage along the translation axis is provided by means of a lead screw 23 driven by a motor 24.

In order to ensure that the disc is translated slowly but without sticking, the arrangement of the lead screw may take the form disclosed in British Patent Specification No. 1,394,430.

The disc 12 carries around its periphery an evenly spaced set of grating lines 25. These grating lines are sensed by an ordinary optical angular position sensor which provides in ordinary fashion signals indicating the rate of movement of the disc in rotation as given by the relative velocity of the grating lines and the encoder. The disc bearing assembly carries a surface 27 which is normal

to the aforementioned translation axis and which is arranged to reflect through a sealed window 28 in the chamber wall 20 a laser beam from an ordinary interferometer arrangement illustrated diagrammatically at 30. The interferrometer can accordingly provide, in well known fashion, signals denoting the rate of movement of the carriage along the translation axis. The rate of translation of the disc is controlled by the rate at which the disc is rotated. The disc 12 and hence the film 11 is rotated by a synchronous motor 31 housed in a sealed enclosure in the carriage which is sealed from the vacuum chamber. The synchronous motor 31 drives the disc at constant speed which may be in the region of 1500 rpm. It will be appreciated that this is a convenient synchronous speed and it is selected because it corresponds to the speed at which a video disc should be rotated during playback.

The signals from the encoder 26 accordingly denote a rate of rotation of approximately 1500 rpm. These signals are compared in frequency with the signals denoting the rate of traverse of the carriage. It is desirable that the frequency of signals denoting the rate of traverse of the carriage and the signals denoting the rotation of the disc be of the same frequency when the disc is being correctly traversed at the right speed but since the speed of rotation is quite high it is necessary to use a divider 32 in order to bring the frequency of the signals from the encoder down to the range of the signals from the interferometer 30. The signals from the divider 32 are compared in phase with the signals from the interferometer 30 by means of a phase comparator 33. Any error signal is amplified by an amplifier 34 and fed to control the motor 24 in ordinary fashion. These arrangements are of an ordinary form normally encountered in a servo-mechanism and their particular construction is not of importance as far as the present invention is concerned. The servo-mechanism could be replaced by an open-loop system in which the lead screw is driven via gearing from the shaft driving the disc or from a second synchronous motor locked in frequency to the motor which provides rotation of the disc. Another possibility is to use an open-loop system but to include the angular position encoder and the interferometer and to feed the error signal from the comparator to adjust by means of deflection plates the position of the electron probe to compensate for slight translational errors.

As has been mentioned, it is necessary, in addition to the deposition of the charge, to heat the thermoplastic film either before or after charge is deposited. It is possible to employ either infra-red or radio frequency heating. In order to avoid excessive heat dissipation, heating should be applied only to a small area of the thermoplastic film just before or just after that area comes underneath the electron probe. The order in which softening and charge deposition take place does not matter. Owing to the small separation of a final lens in an electron optical system for forming the probe and the face of the disc the heater cannot conveniently be located close to the electron probe. Accordingly the heater, denoted by the reference 35, is preferably located at the same diameter of the disc as is the electron probe but on the opposite side of the axis of the disc from the electron probe. However a further possibility consists in delaying heating until after the completion of scanning and then to heat the film by passing current through the disc itself. For this purpose a peripheral region 36 which is annular and a circular central region 37 of the disc may be cleaned of film before the disc is inserted in the vacuum chamber prior to scanning. Subsequent to the scanning, the passage of current between electrodes applied to the regions 36 and 37 produces a radial flow of current through the disc and the heating of it via the passage of current can produce sufficient heat to soften the thermoplastic film. In such a technique it is desirable to shape the disc so that its thickness varies as a function of radial distance in order that the heat dissipation by virtue of the passage of current may be substantially constant over the area that carries the thermoplastic film. Such a technique forms the subject of British Patent Application No. 37329/72 (Serial No. 1,458,002), filed 10th August 1972.

The thermoplastic film can be allowed to cool by thermal conduction into the disc.

Subsequent to recording and as a preliminary stage in the manufacture of disc records from the master recording, the disc may be inverted, rotated and translated in an inverted position while metal is evaporated from a boat which is preferably resistively heated. The disc should be rotated rapidly during this time in order to ensure an even coating of the evaporated metal on to the surface of the film. A solenoid operated shuttered aperture close to the surface of the film may be used to prevent excessive heating of the film by radiant energy from the boat and to avoid coating areas other than the surface of the film. Subsequently the metallised layer can be electroplated to form a self-supporting metal negative which can be used in making disc records. It may be necessary to spray the film with a release agent before it is metallised.

The vacuum in the vacuum chamber at least near the electron probe should be about 10^{-6} torr. However it may not be necessary for both the electron column and the recording medium to be disposed in vacuum. In particular the film itself could be disposed in air. It would be possible for example to

direct the electron beam forming the probe through a window in an enclosure in which the electron column itself is disposed. The enclosure itself would be evacuated. The window could be a thin window of titanium, aluminium or other suitable material which is transparent to a beam of electrons. Provided that the film is disposed with its surface close to the window and the energy of the electron beam is sufficiently high, the beam is energetic enough by the time it strikes the thermoplastic film to permit recording in accordance with the present invention.

It is possible to playback the signal recorded in the groove prior to using the film as a master but after its initial metallising by taking advantage of the variation in secondary emission with varying inclination of an electron probe to the surface of the rippled groove in the thermoplastic film. For example, as disclosed in British Patent Specification No. 1.373,512, it is possible to tilt the disc about its axis of translation so that the electron probe can be directed along and towards the groove but at an acute angle to the surface in which the groove is formed. Preferably this angle is about 45°. A collector may face towards the point of incidence of the electron beam on the recorded surface. The collector may be provided with its axis horizontal and in a direction at right-angles to the axis of translation of the carriage. The collector may comprise a cylindrical metal cage with a shielding mesh towards the disc held at an appropriate voltage such as 200 volts positive. Associated with the collector may be a scintillator disc of plastics material onto which emitted secondary electrons are drawn through the collector mesh. The scintillator disc may be attached to an optical guide of "Perspex" (Registered Trade Mark) which carries light emitted by the scintillator disc to a glass window in the wall of the chamber. A photomultiplier or other photoelectric transducer may be disposed against the glass window to feed a video amplifier which generates an output voltage signal. However this arrangement is in no way essential to the present invention.

Figure 5 illustrates diagrammatically an electron column which can be used to form the electron probe. The column consists of an electron gun 41 constituted by a lanthanum hexaboride rod cathode, a magnetic lens 42, a further magnetic lens 43, a modulating grid 44, a pair of deflecting plates 45 by which the focused spot can be wobbled and a pair of blanking plates 49. The column also includes an ion pump 47 and a differential pumping aperture 48 in the centre of a conical shield 50 for the lowest part of the column.

The column shown in Figure 5 includes, for the sake of convenience of illustration, a stigmator 51. This can take the form of a quadrupole or octupole lens and normally consists of four or eight pairs of deflecting plates in the configuration of a regular polygon. The normal purpose of a stigmator is to correct astigmatism in the focussing of an electron beam. For this purpose it is associated with a stigmator control 52, of known form, which is used to vary the field between the various pairs of plates in order to correct any departure from circular of the focussing of the beam.

The current in the electron probe can be modulated, as is known, by varying the current feed to the modulation grid 44.

Development of Signals For Controlling The Electron Beam

In what follows it will be presumed that it is desired to record a television signal in the form of a frequency modulated carrier signal. However before the apparatus suitable for recording is described, it is convenient to refer firstly to Figure 6 which illustrates one of the methods by which the problem of depositing a relatively wide track of charge using a relatively narrow circularly focused beam of electrons can be overcome. In the method shown in Figure 6 the electron beam is transversely oscillated that is to say wobbled from side to side at a relatively high frequency. Figure 6 illustrates in simplified form the progression of a projection of the beam onto the film which is shown as moving with an effective tangential velocity V_T. It will be appreciated that in practice the beam of electrons is oscillated back and forth along a line fixed in space whereas the film moves but for ease of illustration the focused spot in Figure 6 is shown as progressing over the surface of the film. The effective diameter of the spot is shown at *d* which is approximately 0.65 microns. The beam comes to rest at the extremities of its sideways movement at positions which are fixed in space but as far as the film is concerned the successive rest positions of the beam progress, being located at the successive positions 61, 62, 63, 64, etc. The frequency of transverse oscillation, conveniently termed the wobble-frequency f_{sw}, is such that as far as the film is concerned the alternate positions 61, 63, 65 etc. and 62, 64, 66 etc. are respectively aligned and displaced successively by the beam diameter *d*. It will be seen from Figure 6 that the triangular areas X and Y, which occupy half each of the area of scan between positions 63 and 64 are each scanned twice, the former on the scan between positions 62 and 63 and then on the scan between positions 63 and 64 and the latter on the scan between positions 63 and 64 and then for the second time in the scan between positions 64 and 65. The area Z is scanned first on the scan between positions 64 and 65 and then on the (next) scan between positions 65 and 66 and

so on. Thus apart from the very first scan all the points between the rest positions are covered twice. The parallel lines L1 and L2 denote the extremities of the sideways movement of the beam.

The lines L3 and L4 are spaced inwardly from the lines L1 and L2 respectively and denote the edges of the track of charge that is to be deposited.

Provided that the wobble-frequency is high enough, all the area within the lines L3 and L4 is covered with charge. The lower limit of the frequency is that which, having regard to the diameter of the beam, will ensure deposition of charge twice at every point within the lines L3 and L4. It will be appreciated that the effective tangential velocity V_T varies as the track of charge spirals in towards the centre of the disc and centre of rotation of the film. One method of ensuring that the wobble-frequency is always high enough is to vary the wobble-frequency as a function of the effective tangential velocity. For example, the dimensions of the disc require in practice maximum and minimum tangential velocity of 15.7 metres per second and 7.85 metres per second respectively. Typical values for the upper and lower limits of the spot wobble-frequency may be selected at 24.2 MHz and 12.1 MHz respectively.

Also illustrated in Figure 6 is the case where the frequency of transverse oscillation of the beam is insufficiently high, three successive positions of the spot on the film being shown as positions 71, 72 and 73. It will be apparent in this case that within the area delimited by the lines L3 and L4 there will be very substantial areas which are not covered with charge. In general however it does not matter that the wobble-frequency is higher than the minimum necessary to ensure that the beam deposits charge twice at every point on the track.

It can also be seen with reference to Figure 6 that unless the beam is blanked at the extremities of its side to side movement there will be excessive deposition of charge within the lines L1 and L3 on the one side and the lines L2 and L4 on the other side. The excessive deposition of charge in the places mentioned may adversely affect the quality of the recording and in practice it is very desirable to avoid this vestigial deposition of charge in order to reduce the spacing of adjacent convolutions of the spiral track.

In order to produce a distribution of charge which varies across the width of the track, it is desirable, as well as modulating the intensity of the beam for recording the television signal to modulate the intensity of the beam additionally so that the intensity of the beam is greatest when it is in the middle of the track and least when it is at the extremities of its side to side movement. The variation in intensity of the beam for this purpose is, as can be appreciated from a consideration of Figure 6, at twice the wobble frequency.

In our prior British Patent Specification No. 1,373,511 we disclose the possibility of using a triangle wave of frequency f_{sw} for controlling the transverse oscillation of the beam and a combination of waves at the frequency 2 f_{sw} to control the intensity of the beam. For example, the intensity of the beam may, in addition to its variation by the frequency modulated carrier signal, be subject to variation by a rectangular wave of frequency 2 f_{sw} and amplitude V_T added to a wave composed of sine-squared pulses occurring at a frequency 2 f_{sw} and having an amplitude V_T. It has been found that it is convenient to generate a clock frequency at eight times the wobble frequency and to derive by frequency division sub-multiplies of it which can be combined using a simple high-speed logic circuit into suitable waveforms.

The development of various wave-forms suitable for the control of the intensity of the electron beam and its side to side movement if spot-wobble is used as shown in Figure 7.

Figure 7*a* shows a rectangular wave signal of unity mark-to-space ratio, that is to say a "square" wave at 8 f_{sw}. Figure 7*b* shows a wave similar to the wave of Figure 7*a* but displaced therefrom by 90° in phase. Figure 7*c* shows a wave at four times the spot-wobble frequency. Figure 7*d* is a wave at twice the spot-wobble frequency and Figure 7*e* shows a wave at the spot-wobble frequency. It will be clearly apparent that the waves 7*c*, 7*d* and 7*e* can all be derived from the wave 7*a* by means of simple dividers and the wave 7*b* can be derived from the wave 7*a* using a 90° phase shifter.

From the waves 7*a* to 7*e* all the components of the wave 7*i*, which is a combination of the waves 7*f*, 7*g* and 7*h* can be obtained merely by a simple logic system which acts on the waves 7*a* to 7*e*. Thus, using Boolean algebra, wave form 7*f* changes state when (A+B+C+D=0) and again when $(\overline{A}+\overline{B}+\overline{C}+\overline{D}=0)$, wave-form 7*g* changes state when

$$(\overline{A}+\overline{B}+C+\overline{D}=0)$$

and again when

$$(A+B+\overline{C}+D=0)$$

and wave-form 7*h* changes state when

$$(A+B+C+\overline{D}=0)$$

and again when

$$(\overline{A}+\overline{B}+\overline{C}+D=0)$$

where A, B, C, D and $\overline{A}$, $\overline{B}$, $\overline{C}$, $\overline{D}$, are signals corresponding to waveforms 7*a* to 7*d*, and the inverse thereof respectively. Accordingly all that is required is a logic circuit to produce the eight logic outputs from four inputs and the inverse of each of them. Simple addition of wave-form 7*f*, 7*g* and 7*h* gives wave-form 7*i*. It will be appreciated that the wave-forms 7*f*, 7*g* and 7*h* are selected for determining, respectively, the bottom of the groove 6, the side-walls of the groove 6 and the blanking of the beam of electrons.

The input to the system will be a video signal, conveniently described as having an instantaneous frequency f_a which is by means of a frequency modulator converted to a frequency modulation of a carrier signal. It is found desirable in practice to modulate the amplitude of the frequency modulated signal by the square of the instantaneous signal before it is fed to the grid of the electron column.

Electronic Process of Beam Control Signals

Figure 8 illustrates in schematic form an electronic circuit suitable for processing a video input and for developing signals for application to the grid and spot-wobble plates of the electron column shown in Figure 5 and for use in conjunction with the apparatus shown in Figure 4.

In the system shown in Figure 8, a video input is received at a coaxial terminal 100. From the terminal 100 the input video signal proceeds to a frequency modulator 101 wherein it is incorporated as a modulation on a carrier signal. The input video signal is also fed to an analogue squarer 102 of which the output is proportional to the square of the instantaneous video signal. In the present embodiment it will be assumed that the spot-wobble frequency will vary with time. The signals necessary for deriving the spot-wobble signal and the various groove-shaping signals are generated by a voltage controlled oscillator 103. This oscillator produces an output frequency which can range between 200 MHz maximum and 100 MHz minimum. In this embodiment it is assumed that the spot-wobble frequency will vary as the effective tangential velocity of the disc and for this purpose the frequency of the voltage controlled oscillator is varied by a linear ramp generator 104. This produces a ramp signal which varies according to the value of $k(a-bt)$ where k, a and b are constant and t represents time. The constants are selected so that the value represented by ka causes the voltage controlled oscillator to produce 200 MHz when scanning starts at the outer region of the film and so that the frequency of the voltage controlled oscillator falls to 100 MHz at the end of scanning where the radius of the spiral path is at a minimum and the tangential velocity of the film is effectively 7.85 metres per second. The output from the linear ramp generator is also fed to one input of an anologue multiplier 105 which multiplies the square of the instantaneous video signal with the reciprocal of the output from the linear ramp generator. The output from the multiplier 105 is fed to a modulating input of an amplitude modulator 106 which modulates the amplitude of the frequency modulated carrier signal from circuit 101 in accordance with the output of the multiplier 105. The amplitude modulated, frequency modulated carrier signal produced at the output of the amplitude modulator 106 is fed to a modulating input of another amplitude modulator 107. The amplitude modulator 107 modulates the amplitude of the output of the oscillator 103 with the amplitude modulated, frequency modulated carrier signal so that this latter signal can be conveyed through a high-voltage coupling 108 as a modulation on a multiple of the spot-wobble frequency. The high-voltage coupling, which can be of any suitable form, is employed because the various components of the electron column are at a high voltage relative to ground and the various signals which are used to control the electron beam must be superimposed on the high standing potentials associated with the various components of the electron column. It will be appreciated that by thus effectively combining the signal carrying the video information in frequency modulated form with the signal from the oscillator 103 which is harmonically related to the spot-wobble frequency to produce a composite signal, it is made possible to couple all of the information for controlling the electron beam through a single high voltage coupling channel.

After the output of the oscillator 103 passes through the high-voltage coupling 108 it is fed firstly to a phase-shift network 109 and also to an envelope detector 110. The envelope detector recovers from the modulated output of the oscillator 103 the output obtained from the amplitude modulator 106. The envelope detector is followed by a low-pass filter 111 which is sufficient to allow the passage of the frequency modulated carrier originally obtained at the output of the modulator 101 and after amplification by an amplifier 112 the frequency modulated carrier is fed to the grid 44 of the electron column shown in Figure 5.

The phase-shift network 109 produces outputs spaced by 90° of phase, each at a frequency 8 f_{sw}. One output of the phase-shift network is fed directly to a high-speed gating circuit 113 as a signal A corresponding to the wave-form 7*a* in Figure 7. The signal A is also fed through an invertor 114 to provide the signal $\overline{A}$ to the high-speed

gating circuit. The other output of the phase-shift network 109 is fed to the high-speed gating circuit as signal B corresponding to the wave-form *7b* in Figure 7 and to an inverter 115 to produce the inverse of the wave-form *7b*, namely $\overline{B}$. The signal A is also fed to a binary divider 116 which develops the signal C corresponding to the wave-form *7c* in Figure 7. This signal is fed to the high-speed gating circuit 113 directly and through an inverter 118 to the high-speed gating circuit as signal $\overline{C}$ and also to a further binary divider 117 which produces signal D at twice the spot-wobble frequency and corresponding to the wave-form *7d* in Figure 7. The signal D is fed to the high-speed gating circuit directly and also to that circuit through an inverter 140. The signal D also feeds a binary divider 119, the output of which is the signal shown at Figure *7e*.

The high-speed gating circuit is relatively simple to construct. It has six output lines 113*a*, 113*b*, 113*c*, 113*d*, 113*e* and 113*f* which provide respectively outputs which in Boolean form correspond to

$$A+B+C+D=0\,,$$

$$\overline{A}+\overline{B}+\overline{C}+\overline{D}=0\,,$$

$$\overline{A}+\overline{B}+C+\overline{D}=0\,,$$

$$A+B+\overline{C}+D=0\,,$$

$$A+B+C+\overline{D}=0$$

and

$$\overline{A}+\overline{B}+\overline{C}+D=0\,.$$

The particular arrangement of the high-speed gating circuit forms no part of the present invention. Any suitable form of logic may be used and arranged in accordance with the Boolean expressions given hereinbefore. Reference may be made to "Automatic Digital Computers" by M. V. Wilkes published by John Wiley and Sons Inc. for information on how to construct circuits whose functions are expressed in Boolean algebra.

The three pairs of output lines, the first pair being lines 113*a* and 113*b*, the second pair being lines 113*c* and 113*d* and the third pair being 113*e* and 113*f* are coupled to respective OR circuits 120, 121 and 122. The outputs of these circuits are coupled to the clock inputs of three respective bi-stable latches 123, 124 and 125, and the data inputs of these three bi-stables are fed in common from the output of the inverter 140 which provides the signal $\overline{D}$. The outputs of the bi-stables 123, 124 and 125 are fed respectively to amplifiers 126, 127 and 128. The outputs of the amplifiers 126 and 127 are the signals *7f* and *7g* respectively. It is desirable to vary the amplitude of these signals in accordance with the variation of effective tangential velocity. This quantity is carried as a frequency modulation on the 8 f_{sw} signal that is transmitted through the high-voltage coupling and a DC signal which may be expressed as $k'(a-bt)$ can be recovered from the wobble signal by a frequency discriminator 129. The output of the frequency discriminator can be fed through an amplifier 130 to amplitude modulating inputs of the amplifiers 126 and 127. The output of the frequency discriminator, after amplification by the amplifier 130, is preferably also fed through an analogue DC processor which forms a DC signal proportional to the reciprocal of the effective tangential velocity and the resultant signal controls a current generator 132 which controls a current feed for the cathode 41 of the electron column.

The signal *7e* which is obtained at the output of the divider 119 is fed through a further high-voltage coupling 133 to a triangle wave-form generator 134. The output of the triangle generator is fed to control the spot-wobble plate 45 of the electron column.

It was mentioned earlier that although the spot-wobble frequency can vary in proportion to the effective tangential velocity of the disc this is not essential to the present invention. In particular, if the spot-wobble frequency is set high enough, such as more than 25 MHz, corresponding to a frequency of the controlling oscillator of 200 MHz, the linear ramp generator can be omitted or replaced by a source of a steady voltage for controlling the voltage controlled oscillator. Then the signals which represent the effective tangential velocity in the arrangement of Figure 8 merely become constant.

Astigmatic Focussing of Electron Beam

An alternative manner of performing the invention, which leads to a very considerable simplification in processing, uses astigmatism in the focussing of the electron beam. Electron optical systems can be subject to astigmatism in a manner corresponding to ordinary optical systems. If astigmatism is present in the electron optical system then the electron beam is brought to an elongate focus rather than a circular focus. By way of explanation it can be assumed in the simplest case that the beam is brought to an elliptical focus and that along the major and minor axes of the ellipse the current density follows a Gaussian

curve of which the maximum height is at the centre of the ellipse and whose half-height points determine the focus of a point describing the aforementioned ellipse. The effective diameter of the beam can accordingly be very much less along the minor axis of the ellipse than it is along the major axis. Accordingly by employing astigmatism in the focussing of the beam and ensuring that the astigmatic focus is elongate in a direction across the path along which the track of charge is deposited, the required width of track can be provided without the necessity to oscillate the beam from side to side across that path.

As illustrated in Figure 9 which illustrates the intensities 150 and 151 of the beam in the direction along and across the track respectively, the effective diameter d_1 of the beam in a direction along the progression of the track of charge, is relatively narrow, and lies within the afore-mentioned preferred range of 0.5 to 1 micron, for example, 0.65 microns, and the effective diameter d_2 in the sense across the track is very much larger, for example, 3.5 microns or approximately half that of the desired width of track, which width lies within the afore-mentioned preferred range of 3 to 10 microns. It will be appreciated that if the focus is astigmatic there is very much less depth of field in the focus and the method of recording is accordingly more sensitive to variations in the level of the surface of the thermoplastic film.

Even so the electronic processing does become very simple as is shown by Figure 10 which merely consists of those components of Figure 8 which need to be used in conjunction with the electron column of Figure 5 in the apparatus of Figure 4. The input video signal is fed to the frequency modulator where it is fed through a high-voltage coupling to the grid 44 of the electron column. Figure 10 repeats the illustration of the stigmator control and the stigmator itself in Figure 5. Instead of being used to rectify astigmatism in the focussing of the electron beam the stigmator control can be used to introduce it as described with reference to Figure 9. The adjustment of the stigmator to produce the required elliptical focus is quite straightforward and the method of adjustment merely follows the techniques used normally for adjusting stigmators or quadrupole lenses with the exception that the focus is distorted as necessary to produce the required effective diameters along and transverse the path along which charge is to be deposited by the electron beam.

WHAT WE CLAIM IS:—

1. A method of recording a signal, comprising the steps of: directing a beam of electrons at a thin film of electrically resistive thermoplastic material which is supported by an electrically conductive substrate, modulating the intensity of the beam in accordance with the said signal; moving said film relative to said beam and thereby causing said beam to deposit on the film a continuous track of electric charge of which the density varies along the direction of progression of the track in accordance with the modulations of the intensity of the beam, focussing said beam to produce a focus at the film having an effective diameter (as hereinbefore defined), in a sense along the direction of progression of the track, which is substantially less than the shortest wavelength in said signal in the form of the charge density variations along the track, producing astigmatism in said beam so that the said focus is elongate in a direction transverse the direction of progression of said track and has in the transverse direction a second effective diameter (as hereinbefore defined) which is a substantial fraction of the width of the track, so as thereby to cause said track to be of a width which is significantly wider than the first-mentioned effective diameter and has a charge density which is substantially greater in the middle of the track width than at the edges thereof, heating said film to soften it at least where the charge is deposited, whereby a groove of which the depth varies in accordance with said signal to be recorded is formed in the film, and cooling the film.

2. A method according to Claim 1 in which said signal to be recorded is a television picture signal and in which a carrier signal is frequency modulated by said signal to be recorded, to produce a control signal for modulating the intensity of the electron beam in accordance with the signal to be recorded.

3. A method according to Claim 2 including coupling said control signal through a high voltage coupling to an electron column which produces said electron beam, so as to effect said modulation thereof.

4. A method of recording a signal comprising the steps of aiming an electron column so as to direct a beam of electrons at a thin film of electrically resistive thermoplastic material which is supported by an electrically conductive substrate, moving said film relative to said beam and thereby causing said beam to deposit a continuous track of electric charge on the film, generating a control signal for modulating the intensity of the beam in accordance with the signal to be recorded, focussing said beam to produce a focus at the film having an effective diameter (as hereinbefore defined), in a sense along the direction of progression of the track, which is substantially less than the shortest wavelength in said signal as recorded in the form of the charge density variations along the track, controlling said beam and thereby causing said track to be of a width which is

significantly wider than said effective diameter and to have a charge density which is substantially greater in the middle of the track width than at the edges thereof, coupling, through a high voltage coupling, said control signal to said electron column so as to modulate the intensity of said beam in accordance with the said signal to be recorded, heating said film to soften it at least where the charge is deposited, whereby a groove of which the depth varies in accordance with said signal to be recorded is formed in the film, and cooling the film.

5. A method according to Claim 4, in which the controlling step comprises oscillating said beam from side to side across the direction of progression of said track at a wobble frequency sufficient to ensure the deposition of charge twice on substantially every part of the track, blanking said beam at the extremities of its side to side movement, and varying the intensity of said beam at a frequency which is twice the wobble frequency and so that the beam intensity has an amplitude which is greatest in the middle of the track width.

6. A method according to Claim 5 in which the controlling step further comprises generating a series of harmonically related signals including said wobble frequency and twice said wobble frequency and combining selected ones of said signals to produce a composite signal, and in which said varying step comprises varying said intensity in response to said composite signal.

7. A method according to Claim 5 or Claim 6 in which the oscillating step comprises generating a linear ramp signal, generating in response to the linear ramp signal a wobble signal in a frequency range substantially higher than the highest frequency of said signal to be recorded and wobbling said beam from side to side in response to the wobble signal.

8. A method according to any of Claims 4 to 7 in which the signal to be recorded is a television picture signal and said control signal is a carrier signal, frequency modulated in accordance with said signal to be recorded.

9. A method of recording a signal comprising the steps of directing a beam of electrons at a thin film of electrically resistive thermoplastic material which is supported by an electrically conductive substrate, modulating the intensity of the beam in accordance with the said signal, moving said film relative to said beam and thereby causing said beam to deposit on the film a continuous track of electric charge of which the density varies along the direction of progression of the track in accordance with the modulations of the intensity of the beam, focussing said beam to produce a focus at the film having an effective diameter (as hereinbefore defined, in a sense along the direction of progression of the track, which is substantially less than the shortest wavelength in said signal, in the form of the charge density variations along the track, oscillating said beam from side to side across the direction of progression of said track at a constant wobble frequency which is sufficiently high to ensure the deposition of charge at least twice at every point within the width of the track, blanking said beam at the extremities of its side to side movement, controlling the intensity of the beam so that the track has a charge density which is substantially greater in the middle of the track width than at the edges thereof, said oscillating, blanking and intensity control being such that the track is of a width which is significantly greater than said effective diameter, heating said film to soften it at least where the charge is deposited whereby a groove of which the depth varies in accordance with said signal to be recorded is formed in the film, and cooling the film.

10. A method according to Claim 9 in which the controlling step comprises varying the intensity of the beam at a frequency which is twice the wobble frequency and so that the beam intensity has an amplitude which is greatest in the middle of the track.

11. A method according to Claim 10, in which said controlling step comprises generating a series of harmonically related signals including said wobble frequency and twice said wobble frequency, and combining selected ones of said signals to produce a composite signal, and in which said varying step comprises varying said intensity in response to said composite signal.

12. A method according to any of Claims 9 to 11 in which said signal to be recorded is a television picture signal and in which a carrier signal is frequency modulated by said signal to be recorded to produce a control signal for modulating the intensity of the electron beam.

13. A method of recording a signal comprising the steps of aiming an electron column so as to direct a beam of electrons at a thin film of electrically resistive thermoplastic material which is supported by an electrically conductive substrate, moving said film relative to said beam and thereby causing said beam to deposit on the film a continuous track of electric charge, focussing said beam to produce a focus at the film having an effective diameter (as hereinbefore defined), in a sense along the direction of progression of the track, which is substantially less than the shortest wavelength in said signal in the form of the charge density variations along the track, oscillating said beam from side to side across the direction of progression of said track at a wobble frequency which is sufficient to ensure deposition of charge twice

at every point within the width of the track, blanking the beam at the extremities of the oscillatory movement of the beam, generating a first control signal for modulating the intensity of the beam in accordance with said signal to be recorded, said first control signal comprising a carrier signal which is modulated in accordance with said signal to be recorded, amplitude modulating a signal oscillating at a frequency greater than, and harmonically related to the wobble frequency, in accordance with said first control signal, to produce a second control signal, passing said second control signal through a high voltage coupling, deriving from the output of the high voltage coupling a third control signal at the wobble frequency, for oscillating said beam, and a fourth control signal for varying the intensity of the beam at a frequency which is twice the wobble frequency so that the beam intensity has an amplitude which is greatest in the middle of the track width, and so that the track is of a width which is significantly greater than said effective diameter, and detecting the envelope of the said output of the high voltage coupling to reconstitute the first control signal for modulating the intensity of the beam, coupling said reconstituted first control signal, said third and said fourth signals to said electron column so as to effect said modulating, oscillating and intensity varying of said beam, heating said film to soften it at least where the charge is deposited, whereby a groove of which the depth varies in accordance with said signal to be recorded is formed in the film, and cooling the film.

14. A method according to Claim 13, comprising generating, from the output of the high voltage coupling, a series of harmonically related signals including said wobble frequency and twice the wobble frequency, and combining selected ones of said signals to produce said fourth control signal.

15. A method according to Claim 13 or Claim 14 in which said signal harmonically related to the wobble frequency, and said third control signal are of constant frequency.

16. A method according to Claim 13 or Claim 14, including generating a linear ramp signal, and varying the frequency of said signal harmonically related to the wobble frequency in response to the linear ramp signal, thereby also varying the frequency of the third control signal, and thus the wobble frequency.

17. A method according to any of Claims 13 to 16 in which said signal to be recorded is a television picture signal, and in which said carrier signal is frequency modulated by said signal to be recorded to produce said first control signal.

18. A method according to any preceding Claim in which said film is planar, and said moving step comprises rotating said film in its plane and simultaneously translating said film whereby said track describes a spiral path.

19. A method according to any preceding Claim in which said first-mentioned effective diameter is of the order of 0.5 to 1 microns and the width of said track is of the order of 3 to 10 microns.

20. A method according to any preceding Claim in which the thermoplastic film has in its softened state a bulk resistivity of more than 10^{11} ohm-cm. and a viscosity of the order of 10,000 centistokes.

21. A method according to any preceding Claim in which the thermoplastic film consists of polystyrene.

22. A method of making a record, comprising recording a signal according to the method claimed in any foregoing Claim, depositing a metal layer on said film, removing the metal layer from said film and deriving pressings from the negative recording constituted by the metal layer.

23. A method of recording, substantially as hereinbefore described with reference to and as illustrated in Figures 1 to 4, 9 and 10 of the accompanying drawings.

24. A method of recording, substantially as hereinbefore described with reference to and as illustrated in Figures 1 to 8 of the accompanying drawings.

25. Records when made by a method as claimed in any foregoing Claim.

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FIG.1

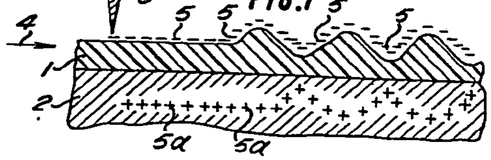


FIG.2A

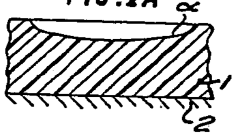


FIG.2B

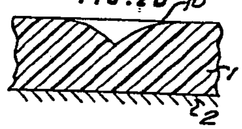


FIG.3

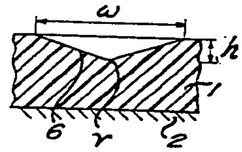


FIG.9

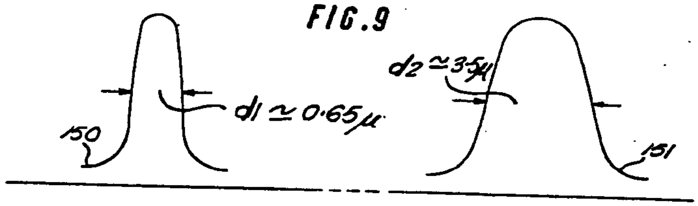
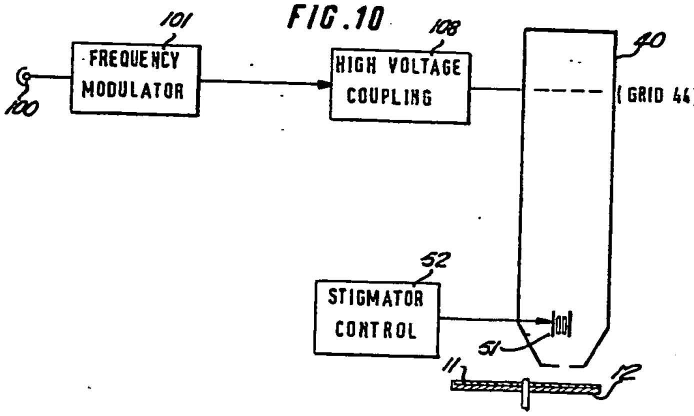


FIG.10



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Sheet 2

FIG. 4

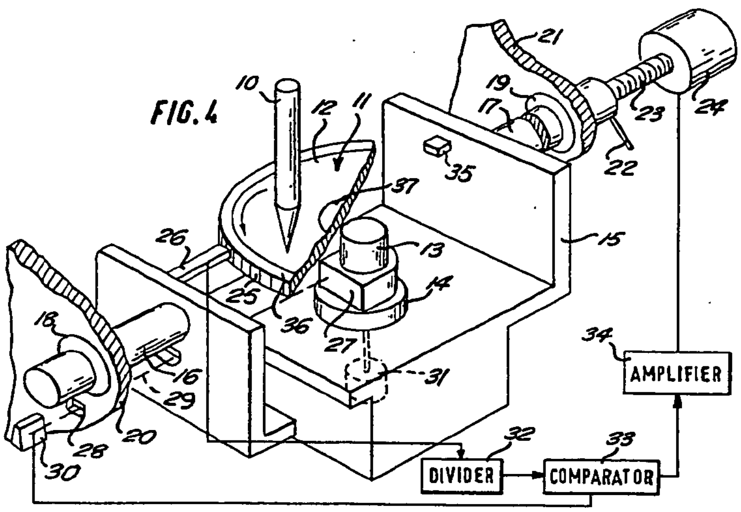


FIG. 5

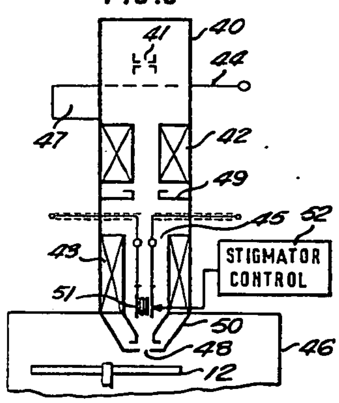
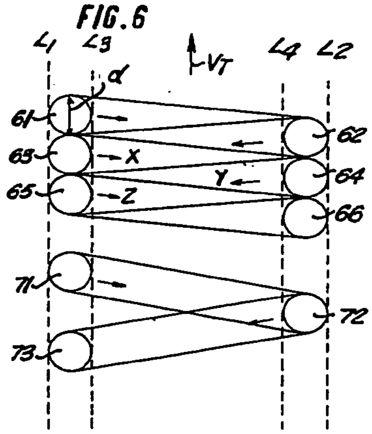


FIG. 6



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Sheet 3

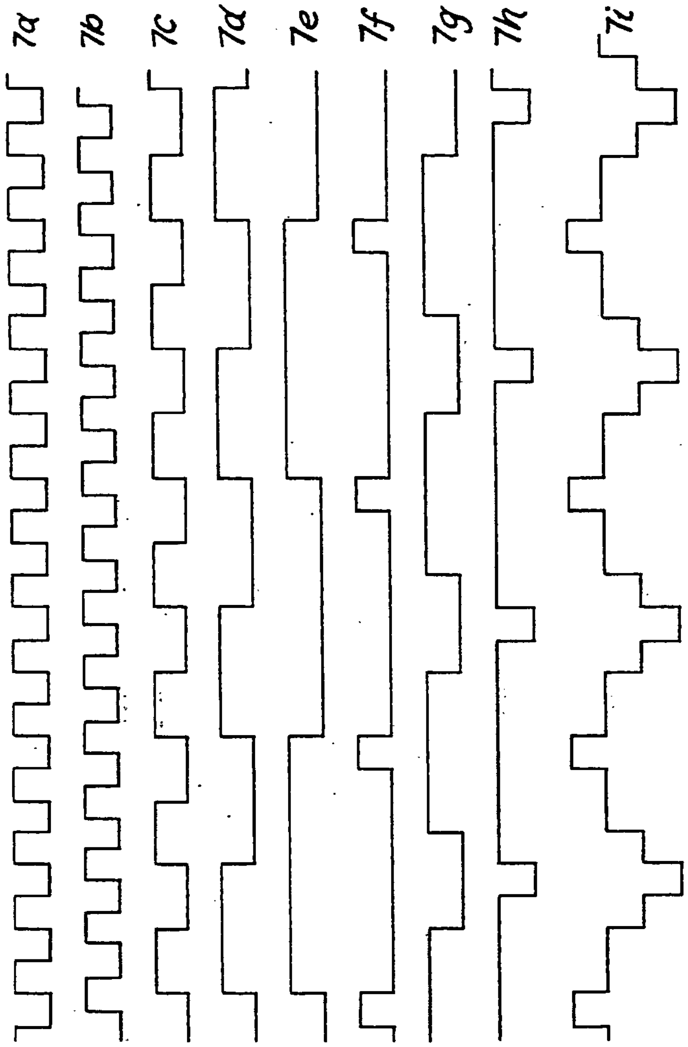

FIG.7

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Sheet 4

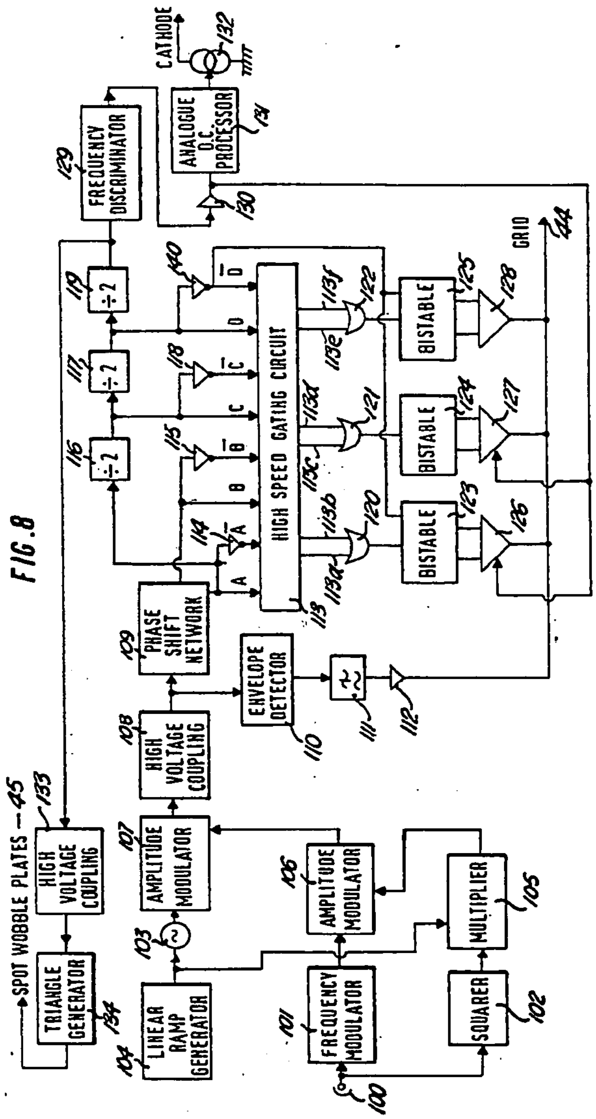

FIG. 8